

APPLICATIONS AND EXTENSIONS OF THE METHOD OF ORDERED MULTIPLE INTERACTIONS

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LONG-TERM GOAL

The primary long term goals of this research is to develop a mathematical technique that will provide analysts with the capability to predict the scattering from ocean and terrain surfaces under the condition of low grazing angle incidence illumination. A secondary goal is to be able to include atmospheric refractivity profiles so as to be able to account for wave refraction particularly in the forward direction. Yet another secondary goal is to provide, where possible, scientific guidelines as to the causes of the dominant behavior to be expected for low grazing angle scattering from the ocean surface.

SCIENTIFIC OBJECTIVES

The scientific objective of this study is to provide insight into and understanding of the complex electromagnetic scattering processes that take place on a rough surface such as the ocean through rigorous modeling, realistic simulation, and efficient computation of the scattering situation. The technology objectives are improved ship defenses, enhanced radar operations during periods of high surface clutter, better remote sensing methods and techniques.

APPROACH

The approach to be followed during this study centers on extending and enhancing a technique developed, in part, under a previous ONR grant. This technique reorders the integral equation describing the electromagnetic current induced on a rough surface by an incident field in such a way that the new equation more nearly replicates the actual physics of the on-surface scattering processes; hence, the name Method of Ordered Multiple Interactions (MOMI). The solution of this reordered equation is, from a computational point of view, significantly more efficient than a standard method of moments technique. This is because it neither requires storage of the impedance matrix resulting from the discretization of the current integral equation nor does it require matrix inversion in determining the discretized current. These two attributes of the technique make it one of the few that is tractable for the low grazing angle incidence geometry.

WORK COMPLETED

A capability to generate two-dimensional (corduroy) rough surfaces having ocean like roughness spectra has been developed. For computational purposes, the Pierson-Moskowitz spectrum has been selected although we have the ability to generate any spectrum of this form. For this

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spectrum and also for a Gaussian spectrum, we have developed a technique for determining how the integral equation should be discretized, i.e., what testing and sampling basis functions are optimum for this problem and with the maximum sampling interval can be used. By selectively attenuating small wavelength ocean waves, we have been able to determine the importance of Bragg waves in low grazing angle scattering. We have developed a capability to account for an atmospheric index of refraction that increases linearly with height above a rough surface and we have carried out initial computations showing the effects of this profile on the rough surface scattering.

RESULTS

One of the most significant results obtained during the past year has been in understanding just how critical certain aspects of the MOMI technique are when dealing with low grazing angle scattering and particularly in the backscatter direction. The integral equation describing the current induced on the rough, conducting surface has a singularity in it that occurs when the integration point sweeps through the point of observation of the current. There are various ways to evaluate the effect of this singularity, but nearly all result in a term that involves the product of the surface curvature and the sampling interval at the point in question. Most investigators have ignored this term based on the use of a small enough sampling interval to drive the term to a small value. However, when dealing with very low grazing angle backscatter from surfaces having a (1-D) spectral roll-off like k^{-3} , we find that this requires unusually small sampling intervals to drive the contribution of this term to zero. Conversely, if the term is retained in the computations, one can obtain the correct answer with a substantially larger sampling interval. The computational cost of retaining this term is minuscule compared to the increased number of computations required when using the small sampling interval. Having solved the issue of whether this term should or should not be included (along with understanding the ramifications of either action), we then turned our attention to the very fundamental problem of determining the minimum sampling interval essential to an accurate solution. Surprisingly enough, this particular problem had an answer (Toporkov & Brown, 1998) and it resulted from examining the Fourier transforms of the “source” and “kernel” terms in the basic integral equation for the current. Such examination showed that these transforms were for all practical purposes bandlimited, i.e., they were essentially zero outside a certain band of spatial frequencies. Thus, using the Nyquist criterion, we were able to determine a minimum sampling interval to have the discretized current samples be sufficient to reproduce the continuous current. Furthermore, by using the Sampling Theorem it then became obvious that the sinc-functions were the proper complete set to be used for both the testing and sampling in the discretization of the basic integral equation. Finally, this led to a clear and unambiguous answer to the problem of how to deal with the singularity in the integral equation.

Our work with including an atmospheric refractivity profile in the technique for dealing with rough surface scattering effects has given us the capabilities to: (a) evaluate various forward scatter approximations, (b) determine just how backscattered energy propagates back to the receiver under this linear refractivity profile, and (c) estimate the effects of this refraction on the statistics of the scattered signal (Awadallah & Brown, 1997). For example, we have determined that it is the large scale surface roughness components that most affect the current sampling interval required to reproduce accurate forward scattering predictions. We are presently going through an extensive set of computations to determine the maximum on-surface sampling interval

which yields an acceptable accuracy in the forward scattered field. Unlike the sampling interval effort described above, this goal is more computationally driven because it aims to answer the same question but for scattering into a much more limited angular range.

Our forward scattering results are not sufficiently far along at this time to be able to say just how good various rough surface forward scatter approximations are. However, we do note that the use of an effective impedance to account for the attenuation of the coherent scattered wave by the surface roughness, is not very good in the off-specular directions.

IMPACT/APPLICATION

Probably the most important near term impact of this research relates to the understanding of what surface roughness features are most important in what angular ranges of the scattering process. For example, this knowledge is absolutely essential in accomplishing remote sensing using either high- or low-resolution sensors. In addition, it is absolutely essential to ship protection using beyond-visual-range sensors since an accurate understanding of exactly what is giving rise to the clutter is a critical component in developing alternate or complementary sensors. Finally, the impact of this research upon personnel training should not be underestimated. If the scattering from the ocean or land surfaces can be accurately understood and modeled, it will be possible to build trainers and simulators to faithfully replicate at-sea conditions without the expense of go to sea!

TRANSITIONS

The basic MOMI technique has been used and is being investigated by Dr. Phuc Tran of Naval Air Warfare Center (China Lake) as a base to develop a code for dealing with full three-dimensional surface roughness. The MOMI method is also being investigated by Dr. Charles Rino for incorporation of rough surface scattering effects in fast split-step forward propagation algorithms. It should be noted that these uses will directly benefit from our most recent improved understandings of the MOMI method.

RELATED PROJECTS

We presently have a Army Research Office sponsored project to investigate and develop better over-terrain propagation prediction methods. Although the primary emphasis of the ARO work is to develop methods to account for surface features such as edges, wedges, and vertices there is clearly a linkage to this ONR-sponsored work.

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